RESPONSE OF MAIZE TO PHOSPHORUS IN SOLE MAIZE AND MAIZE-PIGEONPEA CROPPING SYSTEM IN SEMI-ARID AREAS OF TANZANIA

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A DISSERTATION SUBMITED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN SOIL SCIENCE AND LAND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

Estimating crop response to fertilizer application and identification of effective fertilizer materials is important for plant nutrient management and in sustaining soil fertility. Unlike other agro-ecological zones, no fertilizer recommendations have been established for the semi-arid zones in Tanzania. This could be due to the fact that semi-arid areas are regarded as marginal land for agricultural production. To address this gap, field experiments were carried out to establish phosphorus (P) fertilizer rates and identify the effective P source for semi-arid areas of Kongwa and Kiteto districts in a sole maize and maize-pigeonpea cropping system. Assessment of soil fertility status on experimental sites was carried out. Triple Super Phosphate (TSP) fertilizer was used to test various application rates: 0, 7.5, 15, 30, 45 and 60 kg P ha^{-1}. For P-source triall, Minjingu Mazao, Minjingu hyper phosphate and TSP were tested at 0 and 30 kg P ha^{-1} for each fertilizer material. Sole maize or intercropped with pigeonpea was used as the test crop in two fertilizer trials. The treatments were arranged in a Randomized Complete Block Design (RCBD) with three replications. Soils in the study sites were deficient of P, N and Ca; and had very low organic matter contents. Compared to the control, the fertilizer treatments had higher yield across sites and cropping system. The 15 kg P ha^{-1} fertilizer rate increased the grain yield by 38 to 49% in sole maize and 55 to 60% in maize-pigeonpea intercropping system at Njoro and 51 to 54% in sole maize and 44 to 46% in maize pigeonpea intercropping system in Moleti. Maize yield obtained with 15 kg P ha^{-1} was equivalent to the maximum yield obtained under 30 kg P ha^{-1} fertilizer rate. Maize yield obtained after 30 kg P ha^{-1} fertilizer rate declined slightly possibly reflecting sufficiency level of P. These results suggest that 15 kg P ha^{-1} P is the agronomic P fertilizer rate for maize production under sole maize and maize-pigeon pea intercropping system in semi-arid areas of Kongwa and Kiteto districts, Therefore, application of this

particular rate in maize and maize-pigeon pea cropping system may be an option for the marginal farmers in the region as farmers may reduce the application rate by 50% without losing yield significantly.

Maize grain yield obtained with Minjingu Mazao fertilizer treatment was similar to the yield obtained with TSP fertilizer in Moleti site (3.6 vs. 3.7 t ha^{-1}) and Njoro site (3.9 vs. 4.2 t ha^{-1}). High response of maize to Minjingu mazao is attributed to slightly acidic soil condition, starter N, calcium and fortified micronutrients in this fertilizer material. Thus farmer may use Minjingu mazao or TSP as they are equally suitable P sources in maize production in semi-arid areas of Kongwa and Kiteto districts.

DECLARATION

I AHAZI MKOMA, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

……………………… ………………………….

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The above declaration is confirmed

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Dr. Anthony Kimaro Date

(Co-Supervisor)

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This work is dedicated to my Daughters Sashay, Juliana and Chimwemwe so that this study will be a source of motivation to their education foundations.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIT OF ABBREVIATION AND SYMBOLS

AAS	Atomic absorption spectrophotometer
ANOVA	Analysis of variance
C^0	Degree Celsius
CEC	Cation exchange capacity
cm	Centimeter
CRBD	Completely Randomized Block Design
DAP	Di-ammonium phosphate
EA	East Africa
et al.,	And others
FAO	Food and Agricultural Organization
g	gram
ha	Hectare
ICEAP-00057	Pigeonpea line no 00057
ICRAF	International Centre for Research in Agroforestry
KCl	Potassium chloride
m.a.s.l	Metres above sea level
MHP	Minjingu Hyper phosphate
MT	Metric Tones
Mm	Millimeter
MM	Minjingu Mazao
MRP	Minjingu Rock Phosphate
NBS	National Bureau of Statistics
NPK	Nitrogen, Phosphorus, Potassium
$P<0.05$	Probability level of less than 0.05

pH	Negative logarithm of hydrogen ion concentration
PRs	Phosphate Rocks
SAT	Semi-arid Tropics
SSA	Sub Saharan Africa
TSP	Triple Super Phosphate
USDA	United State Department of Agriculture
%	Percent

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Low soil fertility is the constraint to crop production and productivity on smallholder farming systems in the semi-arid tropics (Bhattacharyy *et al.*, 2013). Semi-arid tropics (SAT) of the world contains about 600 million people who are dependent upon agricultural productions for all or most of their food (Gregory, 1986). Most soils in SAT of Africa are highly weathered and are of low fertility status due to a number of reasons especially erosion by wind. The increase in rural population density and hence increase in land-use intensity are also causing a nutrient depletion among smallholder farming systems (Drechsel *et al.*, 2001). This in turn poses an immediate threat to food production and causes environmental degradation. Management of soil fertility involves, among other things, replenishment of nutrients removed from the soil by crops, leaching and erosion. It is generally known that fertilizer application increases yield and counteracts nutrient deficiency in soils (Kraaijvanger *et al.*, 2014). However, beneficial effects are often realized when the fertilizers are used efficiently at the correct doses.

Maize is one of the most important cereals cultivated in Tanzania. It ranks first followed by rice. Maize is cultivated on average of two million hectares, which is about 45 percent of the cultivated land. It is projected that land under maize cultivation will double by 2050 (Katinila *et al.*, 1998) and fertilizer application will double as well. Maize accounts for 31 percent of the total food production and constitutes more than 75 percent of the cereal consumption in the country (Masawe and Amuri, 2012). About 85 percent of the maize produced in Tanzania is grown by peasants whose farms are less than 10 hectare (Kaliba *et al.*, 1998). However, most of the farmers have an average land area of about

1-2 hectare for cultivation of food and cash crops. Fertilizer application in small land is crucial in order to increase productivity for small holder farmers. For example, Maniafu and Kinyamario (2007) reported an increase in maize yield by 50 percent through fertilizer application in semi-arid areas of Kenya.

Despite the large area under maize cultivation, average yield of maize in semi-arid Tanzania is about 1.2 t ha^{-1} (Mekuria, 2009; Kimaro *et al.*, 2009; Masawe *and Amuri*, 2012). This is by far below the world's average yield which is about 5.2 t ha^{-1} (FAO, 2011) and the national average yield of 4.5 t ha^{-1} (Masawe *and Amuri,* 2012).. One of the major problems constraining maize production is nutrient deficiency (Fageria *et al*., 2006; Brady and Weil, 2008). Evidence of P deficiency has been reported in semi-arid areas of central Tanzania (Mokwunye *et al*.,, 1996; Kimaro *et al.*, 2009; Massawe *and Amuri*, 2012). This was attributed by nutrient removal by crops without adequate fertilization.

In Tanzania increased use of mineral fertilizer by small-scale farmers has been identified as an option for achieving a higher yield and increasing land productivity. Judicious use of fertilizer use is receiving increased attention today because of growing pressure for agriculture to minimize negative environmental impacts. The amount of mineral fertilizer used in Tanzania has increased rapidly over the past decade, from an estimated 80,936 tons in 2002 to 348,938.64 tons 2012 (Kamhabwa, 2014). With reference to the national agriculture sample census of 2012, farmers use fertilizer mostly in cereal crops especially in maize production (Vanlauwe *et al.,* 2004; Kamhambwa, 2014). Maize requires adequate supply of nutrients particularly nitrogen, phosphorus and potassium for good growth and high yield. Sustaining maize production in semi-arid soils is likely to involve, among many other things, substantial use of inorganic fertilizers, especially P-fertilizers (Vanlauuwe, 2011). Use of fertilizer can improve the nutrient balance of soils, which may lead to increases in crop yields. Several studies showed a significant increase of grain yield after mineral fertilizer application (Pinitpaitoon *et al.*, 2011; Kimaro *et al.*, 2009; Chivenge and Vanlauuwe, 2011). However, deficiency in nitrogen and phosphorus has been identified as a major problem affecting crop productivity and potassium is emerging as a potential problem in some parts of the country (Ikerra, *et. al*, 2006). Continuous intensive cropping with insufficient or no fertilizer input is a major contributor to progressive decline in these soil nutrients, resulting in farm households becoming locked into a cycle of declining crop yields and poverty (Semoka, 2002) as cited by Kamhambwa *et al*., (2014).

P-fertilizer recommendations should focus on locally available P sources such as Minjingu hyper phosphate (MHP) and Minjingu mazao (MM) which have been promoted for wider scale use in Tanzania and East Africa (EA) at large (Semoka and Kalumuna, 2000; Semoka and Kalumuna, 1999). Farmers could benefit more by using Phosphate Rocks (PRs) which are less expensive. There are PR deposits in East Africa, which have a promising capacity to alleviate phosphorus deficiency (Jama and Straaten, 2006). The prevailing soil conditions of semi-arid central Tanzania are also conducive for the use of PR. The direct use of PR generally requires P-deficient acidic soils with pH less than 5.5 (Sanchez, 1976; Rajan *et al.*, 1996). This is the case for most soils in semi-arid Kongwa and Kiteto districts (Masawe and Amuri, 2012). In addition Minjingu Phosphate Company has produced a blended product called Minjingu mazao which contains 10% N, 8.8% P, 5% S, 0.5% Zn, 0.5% Cu and 0.1% B. In additional macro and micro nutrients in Minjingu mazao makes it more useful as chemical fertilizer especially in soils with multiple nutrient deficiencies.

1.2 Problem statement and Justification

Matching fertilizer application rates and use of effective fertilizer materials to crop needs is an essential component of optimizing crop production (Amuri *et al.*, 2013). However limited availability of site-specific fertilizer recommendations can undermine yield increment obtained from fertilizer application. The fertilizer recommendations of crops have been researched extensively in agricultural research institutes in different agro-ecological and farming systems in Tanzania since 1980s. Based on these studies, review of recommendations for various agro ecologies was published in 1993 and 2014 (Mowo, *et al.*, 1993: Marandu *et al.*, 2014). However, no recommendation for maize in semi-arid zones of Tanzania has been published so far. Using blanket fertilizer recommendations may lead to low crop responses and poor soil fertility management. This is because blanket recommendations can be higher or lower than crop requirement. The use of site specific fertilizer recommendations by amount and sources is very important for sustaining crop yield and soil fertility (Webb *et al.*, 2011). The need to recommend fertilizers according to the agro-ecological diversity and soils site specific conditions and climate have been reported by Smaling *et al.*, 1992. In semi-arid areas of Kenya, a site specific P fertilizer recommendation of 18 kg P ha^{-1} from Triple Super phosphate (TSP) fertilizers was reported (Mburu *et al.*, 2011). Therefore, in considering a varied agro ecological condition of semi-arid central Tanzania, new site specific fertilizer recommendations for semi-arid agro ecological zone are needed based on soil characteristic and crop responses.

1.3 Objectives

1.3.1 Overall objective

The overall objective of this study was to increase maize yields in maize-legume cropping systems through the use of appropriate fertilizer recommendations.

1.3.2 Specific objectives

The specific objectives were:

i. To assess soil fertility status in selected maize growing areas of Kongwa and Kiteto districts,

ii. To determine maize responses to different P fertilizer rates under maize monoculture and intercropping with pigeonpea, and

iii. To compare the effectiveness of three P fertilizer sources namely; Minjingu Mazao (MM), Minjingu Hyper phosphate (MHP) and Triple Super Phosphate (TSP) on maize yields

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Properties and diversity of soils in semi-arid tropics

The diversity of soils in semi-arid regions is vast. In review of the soils of the SAT, Kampen and Burford (1980) showed that, 70 percent of the total Semi-arid tropics (SAT) are mainly found in Africa and south-east Asia (mostly in India). In Latin America and Australia, semi-arid regions cover about 10 percent. Alfisols and aridisols are the common soil orders in SAT (Vandenbeldt *et al.,* 1990; Kamhambwa *et al*., 2014). In low rainfall areas of Southern Africa the soils vary widely from very extensive areas of arenosols (sands and loamy sands) in Botswana, Zimbabwe and Mozambique, to smaller but potentially important areas of vertisols (heavy clays) scattered widely over the zone; and from highly leached and acid acrisols, ferralsols, and nitosols in which are mainly found in Tanzania Jones, (1984) as cited by Mowo (1993).

Physical properties which adversely affect agriculture on these soils are variable. Low rates of infiltration leading to high run-off. Surface crusting in semi-arid regions may be the primary reason for low infiltration and hence surface crusting hinder seed emergence. Many semi-arid soils have low moisture-holding capacity (Vandenbeldt *et al.,* 1990), especially shallow or sandy soils. This can be due to inherent low moisture holding capacity of sand soils. Chemical soil problems include low fertility which may be inherent or caused by leaching or by past soil erosion. In the Sahelian rangelands, the low fertility of soils, especially in N and P was reported to be more of a limiting factor than low and irregular rainfall. Also many tropical soils have low nutrient content and rely on the recycled nutrients from soil organic matter to maintain fertility (Tiessen *et al.*,, 1994)**.** In SAT regions, the loss of soil, organic matter, and nutrients is a common soil fertility problem. For example, in Semi-arid areas of India, Nigeria and various regions in the world, low Organic Carbon (OC), low total N, low to medium available Phosphorus (P), medium to high potassium (K), low Sulphur (S), Boron (B) and Zinc (Zn) have been reported (Sahrawat and Wani, 2013; Mokwunye *et al.*, 1996; Bationo and Mokwunye, 1991) and are strongly related to little or no replenishment of the soil nutrients.

2.2 Role of chemical fertilizers (N,P and K) in maize production

In every region of the world, the intensification of crop-based agriculture has been associated with a sharp increase in the use of chemical fertilizers (Morris *et al.*, 2007) especially NPK containing fertilizers. Maize is the principal crop grown by farmers and who receives fertilizer through subsidy in Tanzania (Benson *et al.*, 2012). The primary aim of applying inorganic fertilizer is to increase crop productivity and sustain soil fertility (Weight and Kelly, 1999). In doing so, inorganic fertilizer affords both plant productivity gains and sustainable replenishment of nutrients back into the soil. NPK containing fertilizers play an important role in boosting crop production. With fertilizers, crop yields can often be doubled or even tripled (FAO, 2000). However, in spite of their increased application over the years, per hectare yield of crops still remain low in Tanzania compared to other developed countries (Ahmed *et al.*, 2012; USDA, 2011). The available data show that the average crop yield per hectare in the country has declined from 1.4 t ha^{-1} in 2007/08 production season to 1.2 t ha^{-1} in 2009/10 production season (FAO, 2011). Inadequate knowledge on efficient use of fertilizer is among the reasons which lead to low maize production in Tanzania. Low yield obtain by farmers despite use of fertilizer disappoints them and quit from chemical fertilizer application. In 2008, only 9 percent of farmers in Tanzania regularly used inorganic fertilizers on their crops NBS, (2010). However, fertilizer use is considered as lead practice, which predisposes the farmer to adopt other improved practices, thus, recognized as a major factor in increasing food production. Application of P fertilizers especially water soluble P have been reported to increase crop yield when used correctly (Ikerra *et al.,* 2006) especially in degraded soils.

2.3 Influence of P on maize grain yield and biomass yield

Phosphorus is important plant nutrient in maize production as it requires adequate supply of phosphorus for good growth and high yield. In maize production, P is a major yield determining factor and its availability in sufficient quantity is essential for optimum maize growth and yields. P is required in many compounds in cells and organelles and is associated with numerous components of metabolism (sugar phosphates, nucleic acids, nucleotides, coenzymes, phospholipids). It is needed in large quantities, and is often taken up very early in the plant's life, and later moved internally to rapidly growing parts of the plant, meaning it is often concentrated in younger tissues, flowers and seeds (Epstein and Bloom, 2005).

P is one of the most important factors affecting crop growth and yield of maize. Application of P is shown to increase grain and stover weight (Amanullah *et al*., 2010). Phosphorus which makes up 0.1 to 0.4 percent of the dry matter of the plants plays a key role in the transfer of energy. Thus it is essential for photosynthesis and other bio-chemical-physiological processes in the plant. It is indispensable for cell differentiation and for the development of the tissues, which form the growing points of the plant FAO (2000), found that, there was increase in grain protein of about two percent higher in P fertilized grain as compared to control treatment. Furthermore, application of P fertilizer was found to significantly increase in dry matter accumulation in maize.

2.4 Effectiveness of MHP, MM and TSP as fertilizer materials for maize production in semi-arid soils

2.4.1 Minjingu hyper phosphate fertilizers

Phosphorus deficiency is a major nutrient in the farming system which limits crop production in SAT (Kimaro *et al*., 2009). Inorganic fertilizer is a technology that can be used at all scales of agricultural production (Benson *et al.*, 2012). Most of the SAT like *Cutanic Lixisols (Hypereutric Hyperochric Rhodic) and Haplic Luvisol (Hypeueutric Profondic Hromic).* Which are mainly found in SAT of Tanzania are (Meliyo *et al.*, 2014) are low in P and highly acidic (Szilas *et al.*, 2007; Kamhambwa, 2014). These soils constitute about 52% of all the Tanzania soils (Ikerra *et al.*, 2006). In order to enhance crop production, various P fertilizer sources are needed to reclaim soil fertility.

Minjingu Phosphate Rock (MPR) in northern Tanzania with an estimated reserve of 7 million tones consists of two types of phosphate rock including hard Minjingu Phosphate Rock (MPR) and soft MPR. Minjingu phosphate rock (MPR) based fertilizers (Minjingu phosphate and Minjingu mazao) are slow release and cheap source of P available for farmers. These are apatite phosphate and require acid soils, low in exchangeable Ca and available P for effective dissolution (van Straaten, 2002).Both types seem to be promising for direct application as fertilizers. Minjingu hyper phosphate (P_2O_5 – 28-30%, CaO – 38%) is a phosphate rock which works well in acidic soils. The most important property of MHP as fertilizer and agronomic performance is its solubility and reactivity in soils (Mzee, 2001). Mineral reactivity of MHP depends on the chemical and mineralogical composition and crystal size. Therefore, suitability of MHP use depends on factors affecting its solubility, which are its chemical and mineralogical characteristics, soil texture and soil chemical characteristics, especially soil pH, Ca and P content. Research results shows that within 15 days of contact with soil, 50 % of P is solubilized and made available to plant available and equilibrium with soil P is attained within the 50 days (www.minjingumines.com). Semoka and Kalumuna (1999) reported that, under favorable conditions of low pH, calcium and high rainfall, TSP performed better than MHP in the first growing season. This is attributed to slow dissolution of MHP leaving high residual P in soils that lead to its effectiveness in the next growing season. Other study by found that banding of MHP is frequently less effective than broadcasting and incorporating into the soil. This could be attributed to soil erosion and leaching. It has also been reported that, soil incorporation of MHP during planting gave the same yields as TSP indicating that MHP can replace TSP on acid, highly weathered tropical soils low to very low in available P and exchangeable Ca (Szilas *et al.,* 2007)

2.4.2 Minjingu Mazao fertilizers

Use of MPR as an alternative P source to TSP has received attention in Tanzania since the 1960s' (Semoka and Kalumuna 1999; Ikerra *et al.,* 2006). Minjingu Fertilizers Company produces the blend called Minjingu Mazao, which is basically Minjingu hyper-phosphate supplemented with Nitrogen, Sulphur, Zinc and Boron, , (N 10%, P 8.4 %, S 5%, Zn 0.5%, B 0.1%). In addition the product contains 17.4 percent CaO and 1.9 percent Mg which come from the apatite. Minjingu Mazao (MM) being MPR origin is expected to have similar characteristics as MHP except for the added nutrients. Minjingu mazao was introduced to eliminate P deficiency and micro- nutrients as mentioned above. In Tanzania areas of micronutrient deficiencies are becoming widespread (Semoka, J.M.R personal communication, 2014). This could be attributed to low fertilizer analysis of micronutrient and S. The micronutrients and S deficiencies are also common due to continuous cultivation without adequate fertilization. Areas of S deficiency are becoming widespread throughout the world due to the use of high analysis low S fertilizers, low S returns with farmyard manure and high yielding varieties (Arshad *et al.,* 2010). Therefore, MM will be effective even in areas with micro-nutrient deficiencies

2.4.3 Triple super phosphate fertilizers

Triple super phosphate fertilizer is a commonly used chemical fertilizer in semi-arid Tanzania. The fertilizer analysis of TSP (Ca $(H_2PO_4)_2.H_2O$) contains (45% P_2O_5 (0-45-0) and 15% Ca). TSP is manufactured by reacting Phosphate Rock and Phosphoric acid (52% P_2O_5). TSP has the highest P content of dry fertilizers that do not contain N. Over ninety percent of the total P in TSP is water soluble, so becomes rapidly available for plant uptake. As soil moisture dissolves the granule, concentrated soil solution becomes acidic. TSP also contains 15% calcium (Ca), providing an additional essential plant nutrient. TSP is the most desirable for fertilization of leguminous crops, such as Pigeonpea, where no additional N fertilization is needed to supplement biological N fixation.

2.5 Response of maize to P application rates

Despite the increasing importance of maize in Tanzania fertilizer application rates in maize growing area remain low compared to application rates on maize in other developing countries (Heisey *and Mwangi*, 1996). Average of 250,000 MT of fertilizer used in recent years in Tanzania corresponds to national per-hectare (ha) application rate of about 7 kg ha^{-1} for agricultural land and 25.5 kg ha^{-1} of arable land. Relative to other countries in the region, these application rates are considerably higher than Uganda, Kenya and Mozambique. A study by Bekunda *et al.* (2002) reported that fertilizer application rates in Tanzania are slightly higher than those in Kenya but are still much lower than those applied in the developed countries. It has been reported that, maize respond well on application rates of 10- 20 kg P ha^{-1} in order to attain potential yield in semi-arid western Kenya (Jama *et al.,* 1997). Bationo and Mokwunye (1991) reported annual application rate of 15 to 20 kg P ha^{-1} is usually adequate for maize in semi-arid areas

2.6 Effect of pigeonpea-maize intercropping system on P uptake by the pigeonpea.

Pigeonpea (*Cajanus cajan*), is an important pulse crop that performs well in semi-arid tropics where moisture availability is unreliable or inadequate. Being one of the most drought tolerant legumes, pigeonpea has a great potential to increase the sustainability of cropping systems in the arid and semi-arid regions. In Tanzania, pigeonpea is traditionally intercropped with cereals especially maize and sorghum (Kimaro *et al.*, 2009). This could be due to the fact that, pigeonpea has a slower initial growth than maize which helps to reduce inter specific competitions of nutrient through differentiations of peak nutrient demand (Kimaro *et al.*, 2009). Pigeonpea can improve soil fertility from the leaf fall, nitrogen fixation and recycling of the nutrients. Pigeonpea is also known to increase the total available water and phosphorus pool in the cropping system because of its deep rooting system (Adu-Gyamfi *et al.*, 2007). Increased available water can help to increase P solubility especially in semi-arid areas where moisture stress is a common problem. In addition pigeonpea, increases transpiration which create cooler micro climate, which cools the soil and plants. Pigeonpea is more efficient at utilizing iron-bound phosphorus (Fe-P) than several other crop species. This ability is attributed to root exudates, in particular piscidic acid and its p-O-methyl derivative, which release phosphorus from Fe-P by chelating Fe^3. Although pigeonpea can utilize the relatively insoluble Fe-P, intercropped cereals must rely on the more soluble calcium-bound phosphorus. This finding suggests that cultivation of pigeonpea increases total phosphorus availability in cropping systems with low available phosphorus

Many studies show that intercropping maize with pigeonpea reduces yield of maize. It was reported that, maize intercropped with pigeonpea gave lower yield compared to sole cropped maize in semi-arid areas of Kenya (Rao and Mathuva, 2000). In addition a study by Kimaro *et al.* (2009) revealed that, intercropping maize with pigeonpea enhanced maize yield over sole maize only when fertilized with mineral fertilizer especially nitrogen and phosphorus. Another study revealed that, maize yield increases to 20% higher in the maize pigeonpea intercrop supplied with P fertilizer compared to maize monoculture (Lyimo *et al.*, 2012)

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CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study Area

This study was conducted in maize and pigeonpea growing areas of Kongwa district in Dodoma region and Kiteto district in Manyara region (Fig. 1). Kiteto District is located between latitude 4.41^o and 5.97^o S and longitude 36.07^o and 37.40^o E, whereas Kongwa district is located between latitude 5.47^o and 6.26^o S and longitude 36.15^o and 37.08^o E. Generally, the two Districts are located in the agro ecological zone E2.The zone is characterised by medium altitude plains with some hill ranges; mainly medium textured soils with low to moderate fertility (Mowo *et al.,* 1993). The two districts are also characterised by undulating to rolling plains and plateaux with elevation that range between 500 – 1200 m.a.s.l. The amounts of rainfall received vary are unpredictable in terms of on set and distribution over time (Mongi *et al.,* 2010). Soils are diverse but dominated by highly weathered tropical soils (Meliyo *et al.*, 2014). Large part of the two districts are Semi-arid areas and have growing period of 75 – 179 days where the average rainfall ranges from 200 to 800 mm (Bationo *et al.,* 2001). The average annual rainfall in Dodoma region is 560 mm. However, seasonal distributions of rain can be very sporadic with 48% of the rain falling towards the end of the growing season giving little advantage to crop growth and yield (Kimaro *et al.,* 2009). Crops grown in semi-arid zone are sorghum, maize, cassava, Sweet potatoes, finger millet, pigeonpea, lablab, groundnut, Bambara nuts, simsim, soybean, sunflower, tobacco, jatropha, bean, cowpea and castor.

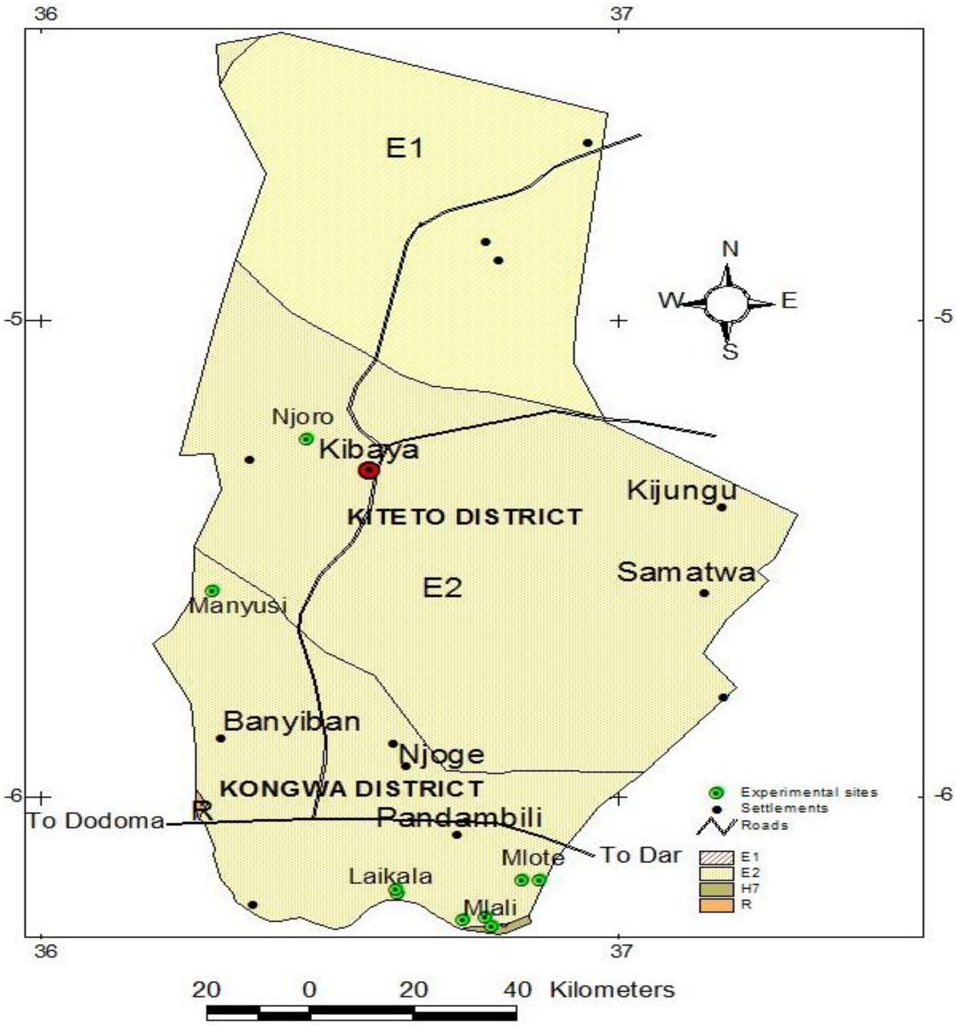

Figure 1: Map of Kongwa and Kiteto showing experimental sites

3.2 Soil sampling for site characterization

Before setting the field experiments, five representative villages were selected for soil sampling. Soil samples were collected in farmer's field where maize and pigeon pea are grown. The village/sites where soil samples were collected are Moleti, Mlali, Laikala, Manyusi and Njoro sites. Soil samples were collected before planting. Composite soils were sampled at 0 - 15-cm depth for soil fertility evaluation. The samples were collected from 12 random points in each study site, mixed thoroughly and quartered every time after mixing, discarded some soil and remain with to average of one kilogram per site. Samples were air-dried and ground to pass through a 2 mm sieve for laboratory analysis.

Samples were analyzed at the Mlingano National Soil Science laboratory for general fertility evaluation of the areas/sites

3.3 Soil analysis

The composite soil samples were analysed for the following physical and chemical properties namely Soil pH, particle size distribution, organic carbon, Cation exchange capacity and base saturation. Others were exchangeable bases namely calcium, magnesium and potassium. Phosphorous and Nitrogen were also analysed.. Soil pH was measured in soil water suspension using a pH meter (Baize, 1993). Soil texture was determined by hydrometer method after dispersing soil with sodium hexa-metaphosphate (calgon), as described by Day (1965). The textural class was determined by USDA textural class triangle (USDA, 1975).

Organic carbon was determined by the wet digestion method of Walkley and Black (Nelson and Sommers, 1982). Total Nitrogen was determined by the micro-Kjeldahl digestion-distillation method as described by Bremner and Mulvaney (1982). Phosphorus was extracted based on Bray and Kurtz-1 method (Bray and Kurtz, 1945) and determined spectrophotometrically (Murphy and Riley, 1962; Watanabe and Olsen, 1965), for soils with pH value of 7 in Moleti, Mlali, Njoro, Manyusi and Laikala village. The cation exchange capacity and exchangeable bases were extracted by saturating soils with neutral 1M NH_4O Acetate (Thomas, 1982) and the adsorbed NH^{4+} displaced by K^+ using 1M KCl and then determined by Kjeldal distillation method for the estimation of CEC of soil. The bases Ca^{2+}, $Mg^{2+,}$ K^+ and Na^+ displaced by NH^{4+} were measured by Atomic Absorption Spectrophotometer.

3.4 Field experiment

3.4.1 Fertilizers and seed variety used

The fertilizers used for this study were TSP 46% P from Yara Tanzania/Chapa Meli (T) Ltd, Minjingu Hyper phosphate (13% P), and Minjingu mazao (8.8% P) from Minjingu Mines and Fertilizer Company and Urea (46% N). Maize variety KILIMA was used as a test crop and was chosen because of its tolerance to drought, popularity to farmers and early maturity of 90-100 days (Kaliba *et al.,* 1998). Pigeonpea variety ICEAP 0057 was used as companion crop and was chosen because of low competition to maize in terms of space and nutrient, early maturity, resistance to diseases and pests (Shiferaw *et al.,* 2005)

3.4.2 Plot size and plant spacing

3.4.3 Njoro experimental site

Plots of 6 by 5 m were laid out, leaving 1-m unplanted buffer strips between each plots and 1.5 m between blocks. Maize was planted at a spacing of 75 cm between rows and 60 cm within rows. Three maize seeds were planted per hill and after germination one inferior seedling was thinned to two plants per hill. Pigeonpea were intercropped in alternate rows. Inter- row spacing of pigeonpea was the same as that of maize but intra-row spacing was 30 cm. One pigeonpea seed per hill was grown. Maize and pigeonpea were planted on the same date.

3.4.4 Molet experimental site

Plots of 4.5 m by 5 m were laid out leaving 1-m unplanted buffer strips between each plot and 1.5 m between blocks. Maize seeds were planted at a spacing of 90-cm between rows and 60-cm within rows. Three maize seed were planted then after germination were thinned leaving two maize plants per hill. Pigeonpea were intercropped in alternate rows. Inter-row spacing of pigeonpea was the same as that of maize but intra-row spacing was 30 cm. One pigeonpea seed per hill was grown. Maize and pigeonpea were planted on the same date.

3.5 Treatments and experimental design

Two experiments were laid out in a Complete Randomized Block Design (CRBD) in two villages namely, Njoro village in Kiteto district and Moleti village in Kongwa district. One experiment for determination of optimum P application rates, and another for determination of effective P sources were established concurrently. Both treatments were tested under sole maize and maize-pigeonpea intercropping system. The treatments were: Control (0), 7.5, 15, 30, 45 and 60 kg P ha^{-1}. The fertilizer used to test these rates was TSP (46% P_2O_5). These rates ranged from micro dosing of P following low phosphorus fixing capacity of semi-arid soils to relatively higher levels that may provide a response curve given course natured texture of the semi-arid soils. The following treatments for P fertilizer sources were adopted in each village: Control (No P fertilizer applied), Minjingu mazao (MM), Minjingu hyper phosphate (MHP) and TSP were applied at the rate of 0 (No fertilizer applied) and 30 kg P ha^{-1}. These fertilizer sources were adopted following the discussions with a Senior Researcher in Semi-arid central Tanzania Dir. Elirehema Swai from Agriculture Research Institute, Hombolo (Swai, E personal communication, 2012).He recommended that, TSP Minjingu Mazao and Minjingu hyper phosphate, are the most preferred P-fertilizer types and are the one offered in the government subsidy programme in semi-arid central and northern Tanzania. Phosphate fertilizer were applied during planting by broadcasting evenly and mixing with soil. Fertilizers were broadcasted due to unreliable rains which lead into inadequate soil moisture. Nitrogen as UREA was applied in two splits: at 21 days after sowing (DAS) and prior to tasselling. The rate of N applied during top dressing was 60 kg N ha^{-1}.

3.6 Management of experimental plots

A routine management of experimental plots was conducted at any time throughout a growing period. Weeding was done two times, one prior nitrogen fertilizer application and the second weeding was done prior maize tasselling. Maize plant with signs of maize streak virus were uprooted immediately after observing clear symptoms diagnosis. Dursbun 48 0EC pesticide was used to control cut worms, aphids, stalk borer and elephant grass hoppers which frequently attached pigeonpea and maize at various stages of growth. It was applied at the rate of 70 mls of Duesbun 480 EC into 15 litre of water

3.7 Maize shoot sampling, sample preparations and analysis

The above ground portions of maize were sampled when maize shoot reached knee height 3-4 weeks after sowing (WAS). Three (one small, one medium and one large) maize plant shoots from the field experiment plot were randomly selected and cut at one cm above the soil surface from each experimental plot. The fresh weight under field condition was measured using an electronic weighing balance and the samples were sent to Seliani Agricultural Research institute (SARI) for oven drying. Plant samples were dried in a forced-air oven at 60 °C to constant weight. The three dried plant samples of each plot were mixed to constitute a composite sample of each treatment

3.8 Harvesting and determination of grain yield

Maize was harvested after maturity from an area of 10.2 m^2 in Moleti site and 9 m^2 in Njoro site, shoot biomass was weighed on electronic weighing balance and moisture content was adjusted to 15%. Fresh weight of the grain was measured at the field and then subsamples of 200 g were taken to the laboratory for oven drying

3.9 Data Analysis

Data on maize grain and dry matter yield were subjected to Analysis of Variance (ANOVA) of Randomized Complete Block Design using Gen STAT Discovery Inc. Version 15th (2012). Where significance existed mean separation was done using Turkey Multiple Range Test Using least significance Difference (LSD) at alpha less than 5% significance level.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Local indicators of soil fertility Status evaluation in the Study Sites

Soil fertility status can be evaluated using local indicators such as high moisture content and retention, occurrence of black soils**,** high clay content in the soils, presence of friable soils**,** high crop yields without the use of fertilizers and manure**,** dense plant population with a variety of plant species**,** vigorous growth of the vegetation**,** and continuous cultivation without decline in crop yields (Kajiru *et al.,* 2014). Based on these indicators, it was noted that more than 70 percent of the soils in the study areas, were deficient in nitrogen and phosphorus. These results are in line with a report by Masawe and Amuri (2012) who noted poor soil fertility in maize growing areas of Kongwa and Kiteto districts. In Moleti soils, striga weed (*Striga hermonthica*) was observed, indicating low soil fertility as striga thrives under conditions of low soil fertility and decreasing plant diversity (Kajiru *et al.*, 2014). In all the study sites, local plants and crops grown (maize) showed nutrient deficiencies symptoms such as purple coloration of leaves and yellowish colour from older to young leaves, indicating deficiencies of phosphorus and nitrogen, respectively (Marschner, 1995).

4.2 Some physical properties in the soils of the study sites

The physical properties of the soils are given in Table 1. According to the USDA textural class triangle, the textural classes for soils from all study sites of Kongwa and Kiteto districts varied from sandy clay loam (SCL), sandy loam (SL) to clay (C).These soils will therefore, have low to moderate water and nutrient retention capacity, and would be more suitable for production of many crops if other soil factors are also favorable.

Table 1: Particle size distribution in soils of the study sites

District	Village/site	Particle size distribution (%)			
		Clay	**Silt**	**Sand**	**TC***
	Moleti	26.00	5.33	68.67	*SCL*
Kongwa	Mlali (Pili)	28.00	6.00	66.00	*SCL*
	Mlali (Lemabi)	58.67	12.00	29.33	*C*
	Mlali (Helena)	19.33	7.33	73.33	*SL*
	Laikala B	39.33	9.33	51.33	*SC*
	Laikala A	16.00	6.00	78.00	*SL*
	Njoro	20.67	8.00	71.33	*SCL*
Kiteto	Manyusi	16.67	10.00	73.33	*SL*

TC* = Textural class; C = Clay; SL = Sandy loam; SCL = Sandy clay loam, SC=Sand clay

However, Mlali Lemabi sites had an average of 59%of clay content Table 1. Krishna (2013) (Un published report) reported that, maize crop growth and maize productions are optimum in sandy soils with clay content of less than 10 percent as well as on loamy or even clayey soils with 30 percent clay. Based on this study, soils from Lemabi site are suitable for maize productions.

4.3 Soil chemical properties

4.3.1 Soil pH

The pH of the soils of the study sites in Kongwa and Kiteto districts ranged from 5.9 to 6.7 Table 2. Landon (1991) classified pH values into four classes, values >8.5 as very high, 7 to 8.5 as high, 5.5 to 7 as medium and <5.5 as low. Therefore the pH of studied soils falls in medium acidic range. Soils with medium pH levels are suitable for most crops. The medium pH values reflect that parent material of the studied soils originally formed from acidic-alkaline rocks. In addition, the studied soils had no problem of base leaching (Thomas and Hargrove, 1984). Also pH is one of the soil properties which influence the dissolution of MHP. Mzee (2001) reported that soils with low pH caused greater dissolution of both North Carolina and Gafsa phosphate rock than soils with high pH. Based on pH range of the tested soils is favorable for use of phosphate rocks as fertilizer materials to address p deficiencies in soils.

	pH	OC	N	P	CEC	Exchangeable bases Ca	Mg	K	EC	BS
	(H_2O)	**(%)**	**(%)**	**(mg kg^{-1})**	**(Cmol $^{(+)}$ kg^{-1})**				**(mS cm $^{-1}$)**	**(%)**
Moleti	5.90	0.51	0.04	4.67	7.25	2.20	1.05	0.66	0.09	57.67
Mlali (Pili)	6.20	0.50	0.05	5.38	6.32	1.90	1.46	0.86	0.08	67.67
Mlali (Lemabi)	6.70	1.34	0.11	6.69	34.61	20.10	7.66	1.39	0.26	84.33
Mlali (Helena)	6.20	0.35	0.04	6.60	5.56	1.70	1.53	0.66	0.09	73.33
Njoro	6.30	0.54	0.05	6.39	8.72	3.87	1.09	0.80	0.06	68.33
Manyusi	6.20	0.72	0.08	7.16	8.20	3.47	1.06	0.76	0.12	68.00
Laikala A	6.30	0.32	0.05	5.16	3.08	1.17	0.36	0.51	0.06	68.33
Laikala B	6.10	1.12	0.08	5.85	7.96	2.64	1.09	1.22	0.11	63.00

Table 2: Selected chemical properties of top soils of maize growing areas in Kongwa and Kiteto Districts

4.3.2 Total nitrogen

Total nitrogen in the soils ranged from 0.04 to 0.11% (Table 2.). Landon, (1991) rated the total N in soils as follows: <0.1%= very low, 0.1% to 0.2% low, 0.2% to 0.5% medium, 0.5% to 1.0 % = high and >1.0% = very high. The soils in Moleti, Mlali and Laikala had very low total nitrogen averaging 0.05%. This suggests that the soils are deficient in nitrogen and will require nitrogen fertilizer to sustain crop production. The soils in Manyusi and Mlali Lemabi farm (Table 2) had amount of total N of 0.08% and 0.11%, respectively which is slightly better as compared to other sites but, is still low for crop production (Landon,1991). Comparatively higher soil total N levels on these sites possibly indicate that, the land was virgin and was used for livestock grazing which may add manure to the soil in Manyusi. The soil in Mlali (Lemabi site) is characterized by alluvial deposit of top soil from other sites due to frequent floods, leading to higher soil nutrients. Therefore levels of total N in Manyusi and Lemabi sites could be relatively higher than a typical content of total N in semi-arid areas of Kongwa and Kiteto (Ncube *et al.*, 2012). The low total nitrogen in Moleti, Laikala, Manyusi, Njoro and parts of Mlali sites was generally due to low organic C because of low biomass production and a high rate of decomposition (Mokwunye *et al.*, (1996).

4.3.3 Organic carbon

Baise (1993), categorised organic carbon as follows; <0.60% very low, 0.6 to 1.25% low, 1.26 % to 2.50% medium, 2.51% to 3.50% high and >3.50% very high. Based on this classification, very low content of organic carbon were obtained at Moleti, Mlali pili, Mlali Herena Njoro and Laikala a Table 2. Very low organic content obtained in the these sites might be due to low additions of organic matter materials into the soils constrained by low vegetation, grazing on farmlands during off season and removal of crop residues for fuel wood or supplementary fodder. Masawe and Amuri (2012) reported similar organic carbon data in semi-arid areas of Kongwa and Kiteto district. The values of organic carbon are measure of organic matter contents in the soil which is also determines soil fertility status. The organic matter helps to improve soil physical, chemical and biological properties such as soil structure, water and nutrients retention.

4.3.4 Available phosphorus

The plant available phosphorus (Olsen P) contents in the soils ranged from 4.67 to 7.16 mg P kg^{-1} soil. According to Landon (1991), all soils of the study areas have low levels of available P, that is <15 mg P kg^{-1}. Maize being a high P-demanding crop, the level of available P values would not meet maize P requirements, hence additions of phosphate fertilizers is inevitable in order to achieve the optimum yield. The low levels of P in these soils could be due to inherent low P from soil parent material. Phosphorus fixation by Fe^{3+}, Mn^{2+} and Al^{3+} could be the root cause for the low extractable P (Schwertman and Herbillon, 1992) and this has been noted for soils at Ihumwa, Dodoma (Kimaro *et al.*, 2009).

4.3.5 Cation exchange capacity

The CEC values ranged from 3.08 cmol $^{(+)}$ kg^{-} in Laikala village to 34.61 cmol $^{(+)}$ kg^{-1} in Lemabi soil at Mlali village and these values range from very low to low in all study sites except for Lemabis soils which is medium (Landon, 1991). The low to medium CEC of the soils could be attributed to the low organic matter contents in the soils as well as the low to medium levels of clay contents.

4.3.6 Exchangeable bases

4.3.6.1 Calcium

The exchangeable Ca in the soil of study areas ranged from 1.17 to 3.87 Cmol $^{(+)}$ kg^{-1} (Table2) . These values ranged from very low, low to medium. Landon (1991) categorized Ca as <2.0 Cmol $^{(+)}$ kg^{-1} very low, 2.0 to 5.0 Cmol $^{(+)}$ kg^{-1} low, 5.1to 10.0 Cmol $^{(+)}$ kg^{-1} medium, 10.1-20.0 high and >20.0 Cmol $_{(+)}$ kg^{-1} as very high. Based on this categorization, the status of Ca in tested soils is very low and medium except for Mlali Lemabi site. In Lemabi soils the higher CEC obtained and inherent rich Ca in parent material could be the reasons of higher amount of Ca in the site. The low status of exchangeable Ca could probably due to low pH, continuous cultivation without fertilizer application.

4.3.6.2 Potassium

The exchangeable K in studied soils ranged from 0.51-1.39 Cmol $^{(+)}$ kg^{-1} as given in (Table 2). Landon, (1991) categorized the exchangeable K in soils as <0.2 very low, 0.2 to 0.4 Cmol $^{(+)}$kg^{-} low, 0.41-1.2 medium, 1.21-2.00 high and >2.00 Cmol $^{(+)}$ kg^{-1} as very high. The soils in the study area had, medium to high exchangeable K, indicating that these soils have adequate levels of K for crop production. Masawe and Amuri (2012) reported same level of exchangeable K in the soils in Kongwa and Kiteto district.

4.3.6.3 Magnesium

The exchangeable Mg in the soil tested ranged from 0.36-7.66 Cmol $^{(+)}$kg^{-1} (Table 2). The levels of exchangeable magnesium in all soils from the study areas were low (<0.4 Cmol $^{(+)}$kg^{-1}) to medium. The low values of Mg $^{2+}$ may be due to high pH (6.7) of this site. Soils from Lemabi site had high exchangeable magnesium. This could be due to inherent dolomite parent rock found in the site.

4.3.7 Base saturation

The base saturation in soils tested ranged from 57.67 to 84.33 % as shown (Table 2). Landon (1991) reported that base saturation is an indication of soil fertility. The general interpretation of base saturation is as follows low <20%, medium 20 to 60%, high >60%. Based on this categorization, 10% of the soils are medium the rest have high level of base saturation. Possibly the studied soil had low Aluminium toxicity as exchange bases are reduced in presence of higher amount of Aluminium contents.

4.3.8 Response of P application rates on maize shoot biomass yield at Kongwa Kiteto districts

The effects of P application rates on maize biomass yield under maize monoculture and maize-pigeonpea intercropping in Moleti and Njoro sites are presented in Figs. 2 and 3. Irrespective of slight differences in agro-ecological conditions of the two study sites, all of the fertilizer treatment significantly ($p<0.05$) increased yields compared to the control. This indicates that, there is a need to fertilizer in maize production in all the study sites. In all sites maize plants in the control, and 7.5 kg P ha^{-1} treatments, showed nutrient deficiency symptoms especially P deficiency as early as two weeks after planting. In the two treatments about 30% of plants were purple in color in the older leaves. At Moleti village the lowest biomass yield was obtained in the control treatment which ranged from 1.95 t ha^{-1} to 2.16 t ha^{-1} in maize-pigeonpea intercropping and maize sole planting. The same trend of lowest yield was obtained in Njoro village, where the lowest biomass yield was obtained in the control treatment which ranged from 1.80 t ha^{-1} in sole maize to 2.23 t ha^{-1} in maize-pigeonpea intercropping system (Figs 2 and 3).

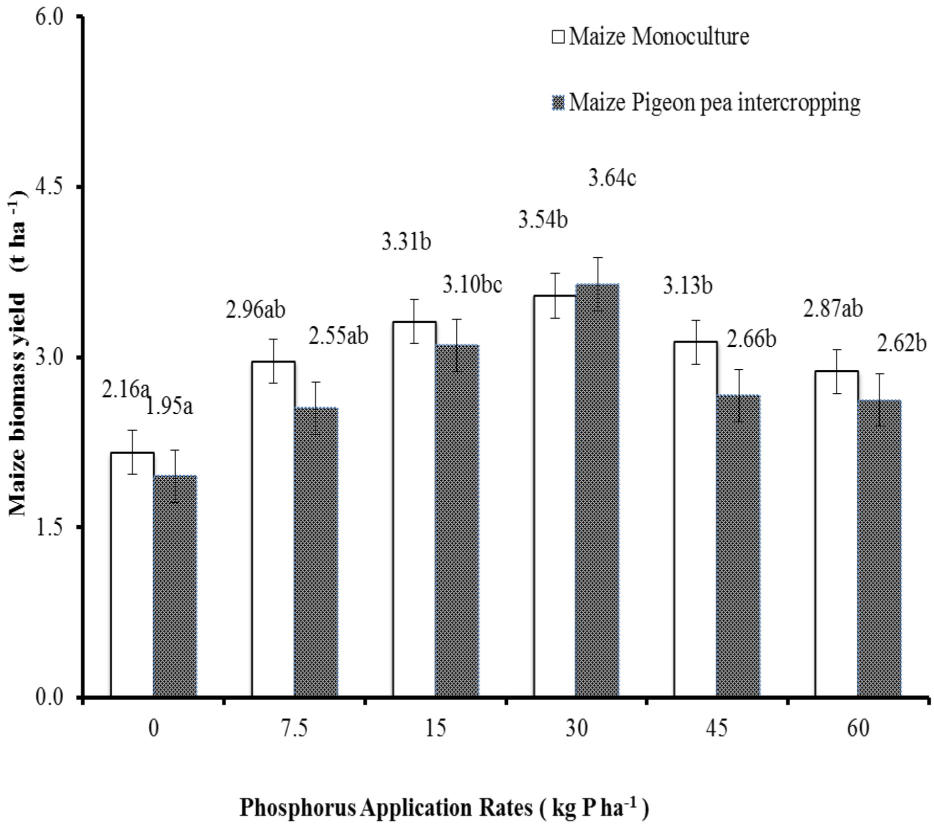

Figure 2: Response of P application rates on maize shoot biomass yield at Moleti site, Kongwa district. Means within a cropping system (sole maize or maize-pigeonpea intercropping system) bearing the same letter(s) are not significantly different at p<0.05 according to Turkey's multiple range test

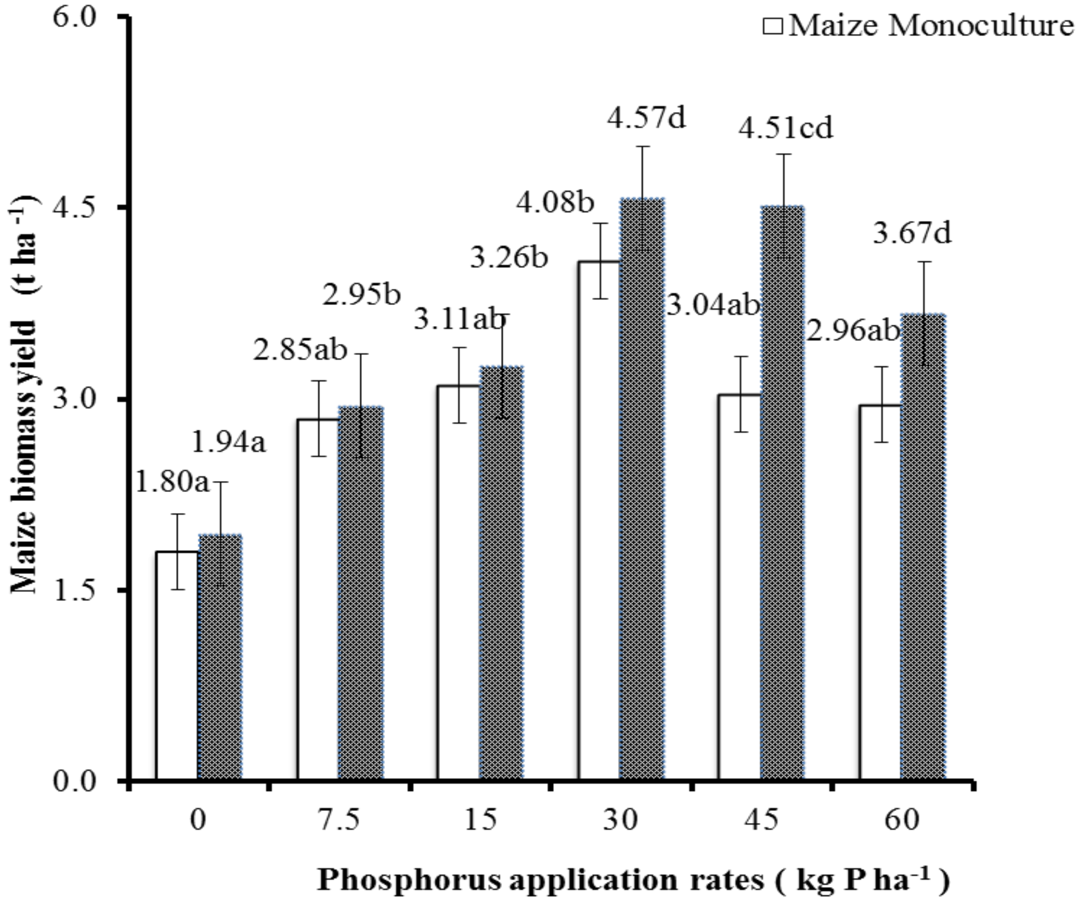

Figura 3: Response of P application rates on maize shoot biomass yield at Njoro site, Kiteto district. Means within a cropping system (sole maize or maize-pigeonpea intercropping system) bearing the same letter(s) are not significantly different at $p<0.05$ according to Turkey's multiple range test

Generally the trend of biomass yield increased with increasing fertilizer application rates. The increase of biomass yields at 7.5 kg P ha^{-1} ranged from 36% to 34% at Njoro and from 27% to 23% in Moleti village. Across sites and cropping systems shoot biomass yields obtained at 15 kg P ha^{-} were statistically similar to the yield obtained at 30 kg P ha^{-1}. The maximum biomass yield was obtained with application of 30 kg P ha^{-1} across all sites (Figs 2 and 3). However, increase in maize biomass yield was comparatively higher in maize monoculture than in intercropping system at the same rate of application. Application of P fertilizer at 30 kg P ha^{-1} gave 56% to 57 % increase in biomass yield at Njoro village and 38% to 46% at Moleti village. In addition, the increase in biomass yield was lower in Moleti site as compared to the yield increase in Njoro site (Figs. 2 and 3). As expected, higher maize biomass response to fertilization under monoculture compared to intercropping system suggests that there was inter competition of added P in soils by maize and pigeonpea. Kimaro *et al.*, (2009) also observed that competition for P reduced yield of maize under intercropping in semi-arid central Tanzania. Furthermore, site differences in maize response to P-fertilization suggest that the response to applied P may be site specific depending on the level of P in soil and other chemical properties such as sesquioxides, which affect soil P availability. Across sites biomass yield tended to decline with increasing P fertilizer application rates of 45 kg P ha^{-1} and 60 kg P ha^{-1}. Relative to 30 kg P ha^{-1} the biomass yield was reduced by 20% and 21% at application rate of 45 kg P ha^{-1} and 60 kg P ha^{-1} respectively. These results suggest that applying P at the rate of 45 and 60 kg P ha^{-1} is wasteful of fertilizer and it may result into reduced economic returns.

4.3.9 Response of P sources on maize shoot biomass yield at Kongwa and Kiteto Districts

Responses of crops to various fertilizers are very important on fertilizer use efficiency. All fertilizer treatments produced significantly higher maize shoot biomass yield than the control treatment (Figs. 4 and 5). Across sites yield increase due to Minjingu Hypophosphate application in maize shoot biomass ranged from 5% to 36% from maize grown under monoculture and 28% to 37 % from maize grown under maize pigeonpea intercropping systems (Figs. 4 and 5). The yield increase due to Minjingu mazao application in maize shoot biomass ranged from 40% to 48% under monoculture and from 44% to 51% intercropping system (Figs. 4 and 5).

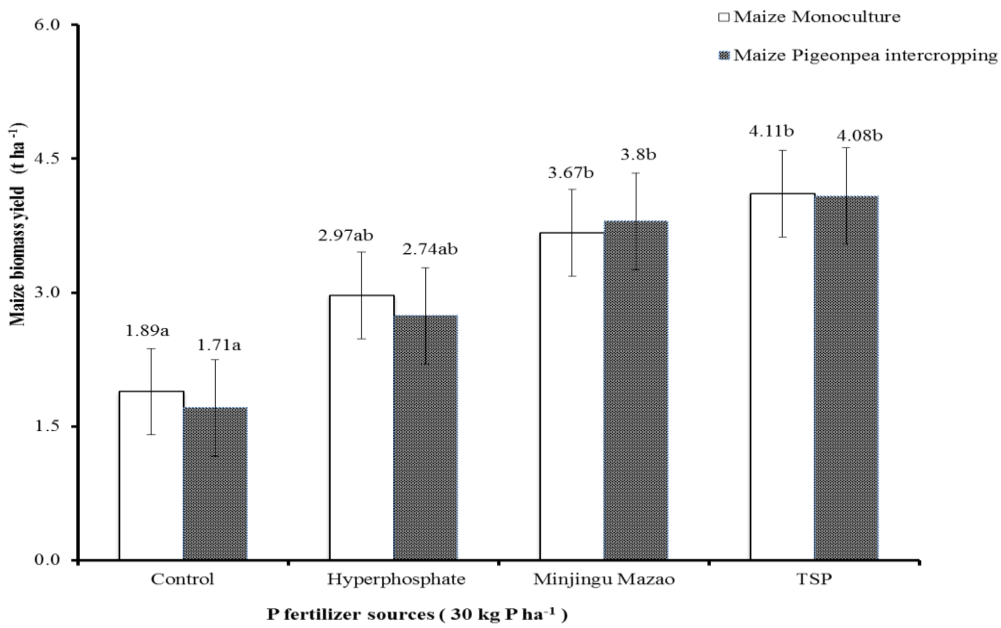

Figura 4: Response of P sources on maize shoot biomass yield at Moleti site, Kongwa district. Means within a cropping system (sole maize or maize-pigeonpea intercropping system) bearing the same letter(s) are not significantly different at p<0.05 according to Turkey's multiple range test

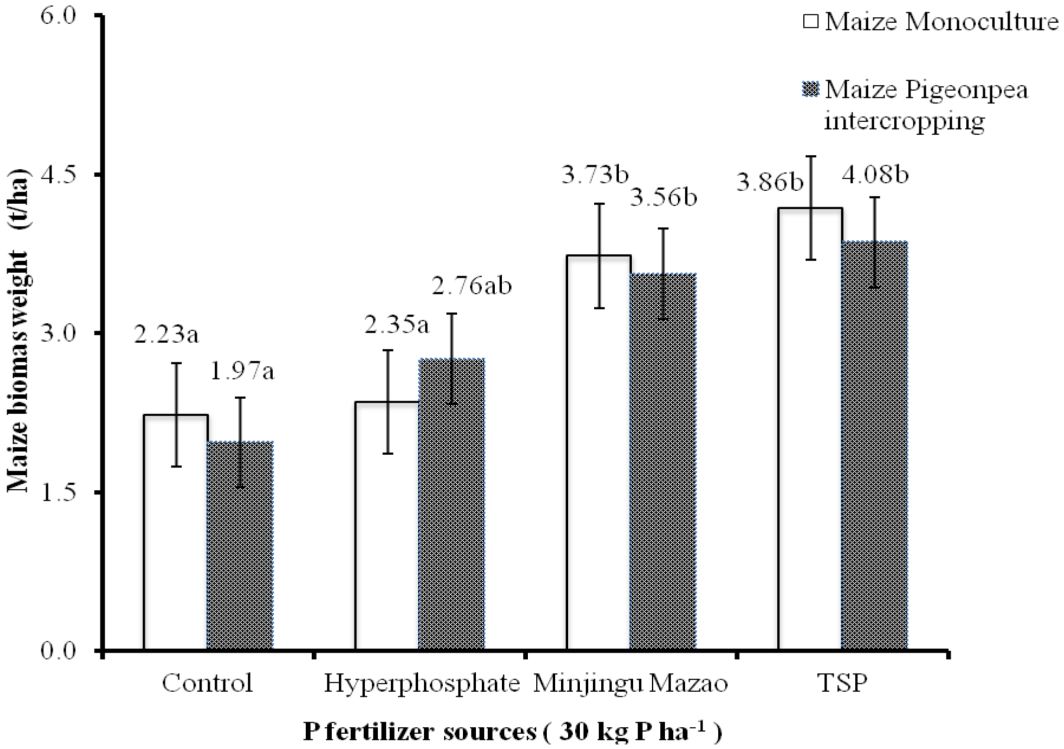

Figura 5: Response of P sources on maize shoot biomass yield at Njoro site, Kiteto district. Means within a cropping system (sole maize or maize-pigeonpea intercropping system) bearing the same letter(s) are not significantly different at p<0.05 according to Turkey's multiple range test

TSP and Minjingu mazao significantly improved maize biomass yield relative to the control, with the highest yield obtained by TSP in both Njoro and Molet sites (Figs. 4 and 5). The yield increase due to TSP application in maize shoot biomass ranged from 46% to 54% for monoculture and 48% to 58% under maize intercropping systems (Figs. 4 and 5). Maize biomass yield in Njoro soils was comparatively higher than corresponding yield in Moleti soils, indicating that Njoro soils are relatively more fertile than Moleti soils as noted for soil P (Table 1). In both sites, maize biomass yield in Minjingu hyper phosphate and control treatments were similar. This could be possibly due to slow solubility of MHP especially in semi-arid environment where the amount of rains received per season is very low to facilitate faster solubility.

4.3.10 Response of P application rates on maize grain yield at Kongwa and Kiteto districts

The effects of P application rates on maize grain yield at Njoro, and Moleti sites, are presented on Figs 6 and 7. All fertilizer treatments produced higher maize grain yield than the control treatment irrespective of cropping system in the two study sites. The 15 kg P ha^{-1} fertilizer rate increased the grain yield by 38 to 49% in sole maize and 55 to 60% in maize-pigeonpea intercropping system at Njoro and 51 to 54% in sole maize and 44 to 46% in maize pigeonpea intercropping system in Moleti. However yield obtained by this rate were not significantly different to the control. Maize yield obtained with 15 kg P ha^{-1} was equivalent to the maximum yield obtained under 30 kg P ha^{-1} fertilizer rate. Maize yield obtained after 30 kg P ha^{-1} fertilizer rate declined slightly possibly reflecting sufficiency level of P. Across sites the highest grain yield was obtained with application of 30 kg in both maize monoculture and intercropping treatments and started to decline with application rates of 45 and 60 kg P ha^{-1}. Mburu (2011) and Jamal (1997) recommended P application rates of 18-20 kg P ha^{-1} for semi-arid areas of Kenya. The rates obtained in current study rates of P fertilizer may be of significant importance in semi-arid Tanzania because soil nutrient depletion in Africa is occurring at an alarming rate and represents the primary cause of declining per capita food production in this region (Sanchez *et al.*, 1997).

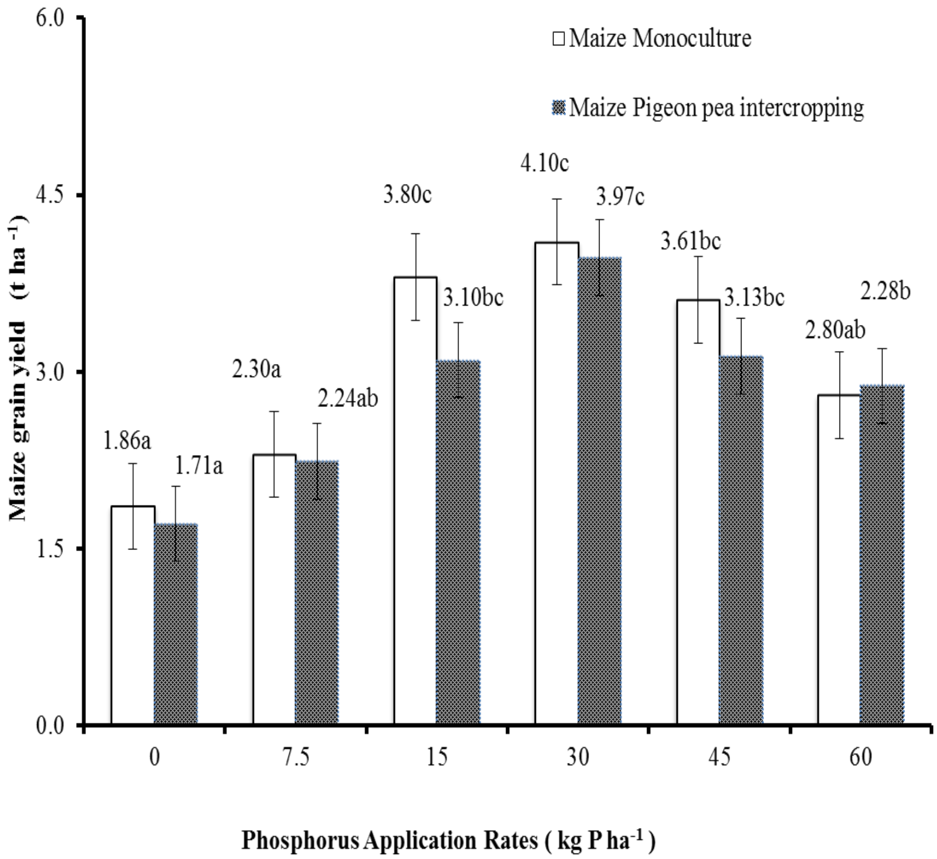

Figura 6: Response of P application rates on maize grain yield at Moleti site, Kongwa district. Means within a cropping system (sole maize or maize-pigeonpea intercropping system) bearing the same letter(s) are not significantly different at p<0.05 according to Turkey's multiple range test

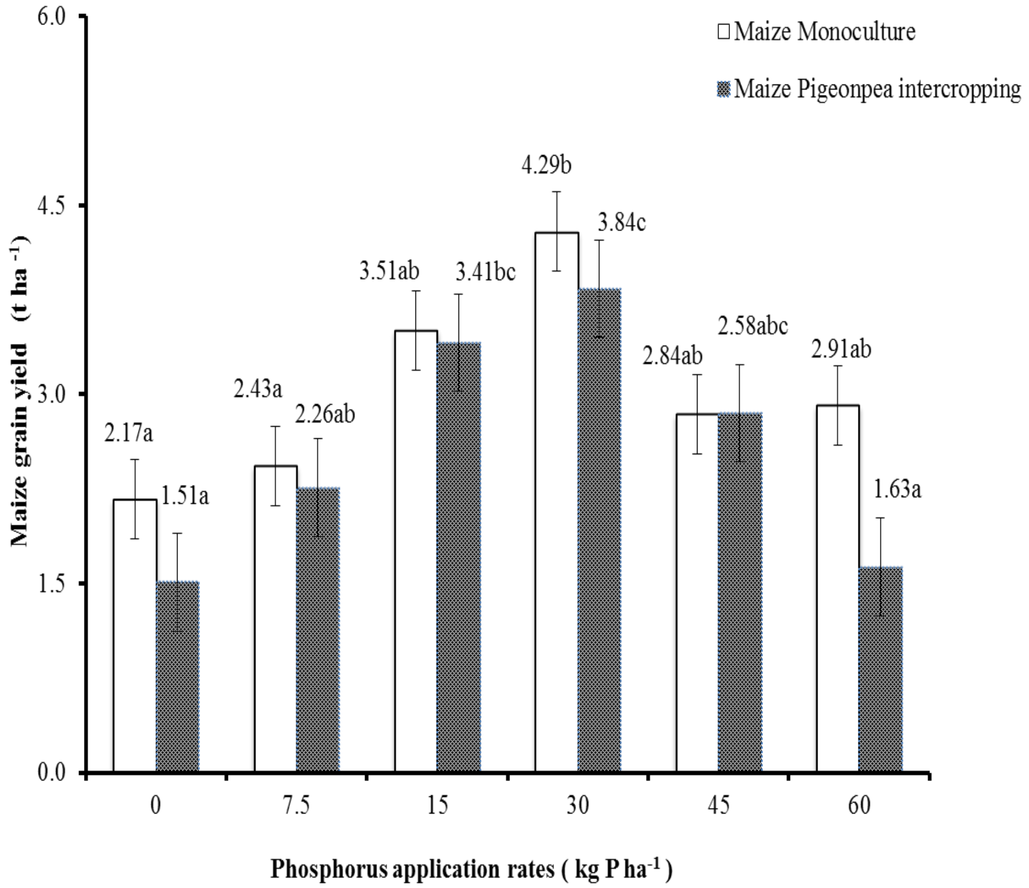

Figura 7: Response of P application rates on maize grain yield at Njoro site, Kiteto district. Means within a cropping system (sole maize or maize-pigeonpea intercropping system) bearing the same letter(s) are not significantly different at $p<0.05$ according to Turkey's multiple range test

Maize grain yield under sole maize cropping at P-fertilizer application rate of 30 kg P ha^{-1} was 4.3 t ha^{-1} and 4.10 t ha^{-1} at Njoro village and Moleti village, respectively. The corresponding yield under maize-pigeonpea intercropping was 3.8 t ha^{-1} and 4.0 t ha^{-1}. Generally these results indicate maize yield is higher in Njoro than Moleti reflecting high potential on this site due to more rainfall and better soil conditions, especially P content Table 1. Comparatively, lower maize yield in Njoro village under intercropping suggest that pigeonpea possibly grew more vigorously in Njoro and hence having suppressing maize yield more than those growing under poor site conditions in Moleti. However overall maize yields obtained under maize-pigeonpea intercropping systems is comparatively lower than yield obtained under the maize monoculture cropping arrangement. This suggests that there is inter specific competition suppressing maize yield. However the yield loss in intercropping can be complemented by yields of pigeonpea but pigeonpea data were not yet available to confirm this claim.

4.3.11 Effects of P fertilizer sources on maize grain yield

Effectiveness of P sources is a useful tool in determining the ability of new or alternative fertilizer to supply nutrients relative to a standard fertilizer source. The effects of P fertilizer sources on maize grain yield grown in Njoro and Moleti are presented in Figs 8 and 9. All fertilizer treatments produced significantly higher grain yield than the control treatment Figs 8 and 9. As mentioned earlier, these results indicate that soils across study sites were deficient in nutrients especially N and P (Table 1) and that fertilizer application is crucial for maize production in Kongwa and Kiteto district. Across sites, the grain yield increase due to application of Minjingu hyper phosphate fertilizer application ranged from 31% to 33% for maize monoculture and 8% to 11% for maize pigeonpea intercropping system. Grain yield increase due to application of Minjingu mazao fertilizer ranged from 51% to 57% for maize monoculture and 38% to 55% under maize pigeonpea intercropping. Furthermore, yield increased due to application of TSP fertilizer ranges from 52 to 60% in maize monoculture and ranges from 44% to 59% in pigeonpea intercropping. The highest grain yield (4.25 t ha^{-1}) was obtained at Njoro village by the application of TSP fertilizer followed by TSP fertilizer treatment at Moleti (3.67 t ha^{-1}). The result also suggests that fertilizer response to maize is higher under monoculture than when maize is intercropped with pigeonpea possibly due to interspecific competition as discussed earlier.

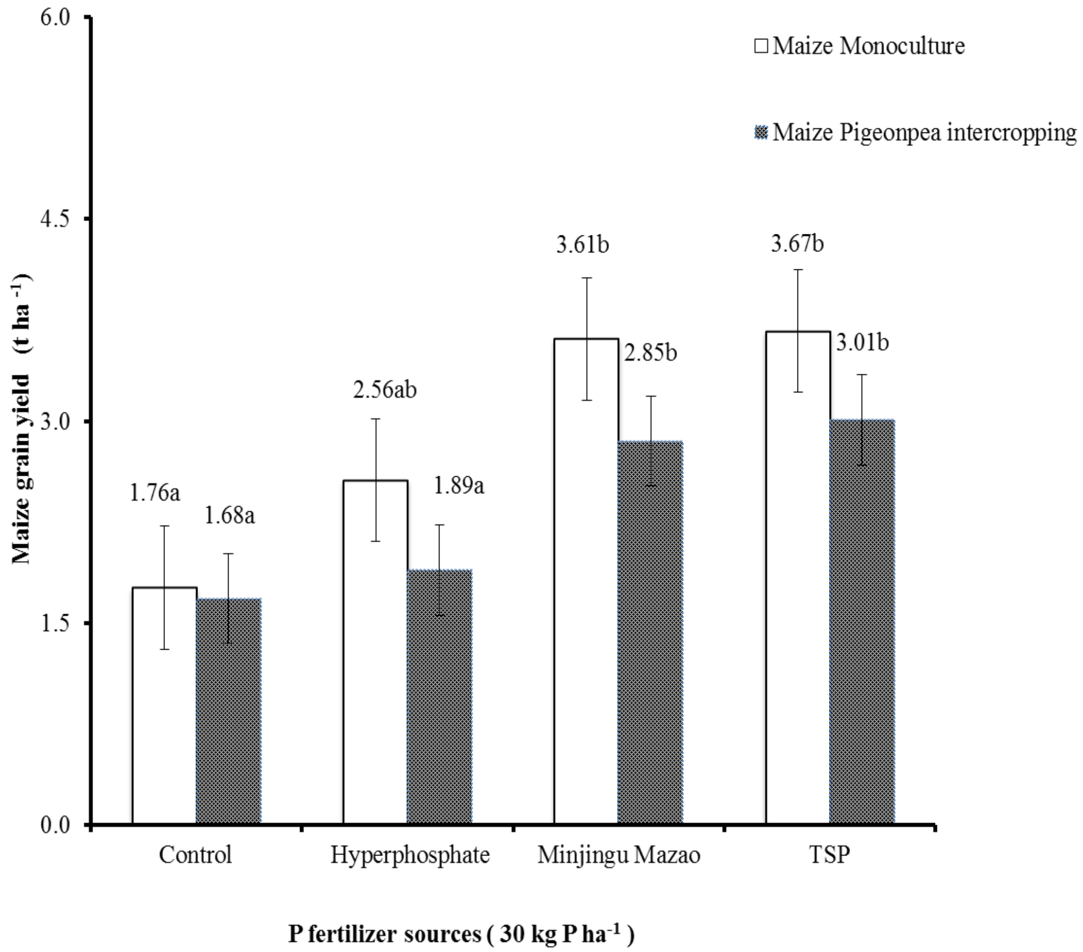

Figura 8: Response of P sources on maize grain yield at Moleti site, Kongwa district. Means within a cropping system (sole maize or maize-pigeonpea intercropping system) bearing the same letter(s) are not significantly different at $p<0.05$ according to Turkey's multiple range test

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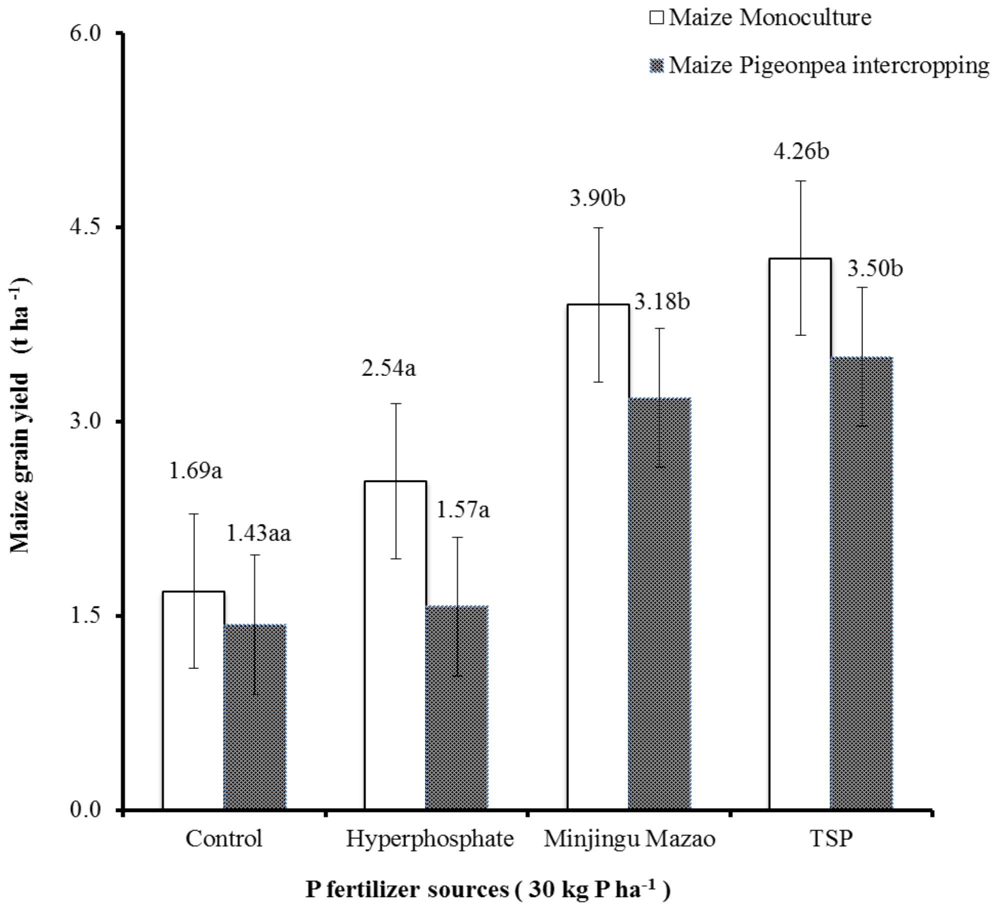

Figura 9: Response of P sources on maize grain yield at Njoro site, Kiteto district. Means within a cropping system (sole maize or maize-pigeonpea intercropping system) bearing the same letter(s) are not significantly different at $p<0.05$ according to Turkey's multiple range test

TSP and Minjingu mazao fertilizers consistently had higher maize yield than Minjingu hyper phosphate in Moleti and Njoro sites. However, maize grain yield obtained with Minjingu mazao was similar to that obtained with TSP in these sites. Better performance of Minjingu Mazao was probably due to the other nutrients found in it (i.e. 5% S, 0.5% Zn, 0.5% Cu and 0.1% B). These results are contrary to those reported by Jama and van Straaten (2006) who found that, Minjingu Hyper phosphate was equally effective as Triple Super Phosphate. Results under current study suggest that Minjingu mazao may substitute TSP in some maize growing location and soils without compromising maize yield.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study focused on developing fertilizer recommendations and evaluated the effective P source for maize in semi-arid zones of central Tanzania. Generally there was positive response to fertilizer application in all sites and maize biomass and grain yield possibly due to low as evidenced from the soil analytical data. From the maize response to P applied as TSP Minjingu Mazao, and Minjingu Hyper phosphate data, it could be concluded that, application rates and sources. The use of fertilizers to replenish soil nutrients for sustainable maize production in this semi-arid zone of Kongwa and Kiteto District is inevitable because most soils have multiple nutrient deficiencies especially P, N, Ca, and Mg however, K is adequate.

1. The soil fertility limitations from the study sites are low plant available N, P, Ca and mg
2. Two sources of P namely TSP and Minjingu Mazao are equally suitable as P sources for maize production in semi-arid areas of Kongwa and Kiteto districts hence farmers can either use TSP or Minjingu mazao depending on availability of either in the market.
3. P application rate of 15 Kg P ha^{-1} and 30 kg P ha^{-1} result into higher maize grain yield farmers can choose either rate depending soil management plan

5.2 Recommendations

a) P application rate of 15 kg P ha^{-1} is recommended as an optimum rate for maize production in Kongwa and Kiteto districts and other sites with similar site conditions.

b) Minjingu mazao is recommended as an effective and locally available source of P for maize production in semi-arid areas of Kongwa and Kiteto districts.

c) More field experiments be conducted to verify the results obtained in the current study

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